

PB84-244144

Occurrence of Aluminum in
Drinking Water

(U.S.) Health Effects Research Lab.
Cincinnati, OH

1984



U.S. Department of Commerce
National Technical Information Service

NTIS

TECHNICAL REPORT DATA		
(Please read instructions on the reverse before completing)		
1. REPORT NO. EPA-600/J-84-082	2.	3. F PB84-244144
4. TITLE AND SUBTITLE The Occurrence of Aluminum in Drinking Water (Journal Version)	5. REPORT DATE 1984	
	6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) Robert G. Miller, Frederick C. Kopfler, Keith C. Kelty, Judy A. Stover, and Nancy S. Ulmer*	8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS CSSB/TMD/HERL/*MERL/USEPA 26 West St. Clair Street Cincinnati, OH 45268	10. PROGRAM ELEMENT NO. ABM61A	
	11. CONTRACT/GRANT NO.	
12. SPONSORING AGENCY NAME AND ADDRESS USEPA/ORD/HERL Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED	
	14. SPONSORING AGENCY CODE EPA-600/11	
15. SUPPLEMENTARY NOTES JOURNAL OF AMERICAN WATER WORKS ASSOCIATION Vol. 76, January 1984, pp. 84-91		
16. ABSTRACT This study has presented data relative to the source of aluminum in drinking water supplies and if in fact aluminum routinely exists in drinking water. The data have shown that aluminum is more likely to exist in surface water sources than in ground water; that only 10% of the ground waters have detectable amounts of aluminum while 79% of the surface water have detectable aluminum. In finished waters, aluminum exists routinely above 0.014 ppm. When coagulating with alum there is a 40-50% chance that the concentration of aluminum will increase above the original raw water concentration. The concentration of aluminum in the Finished Drinking Water does not seem to be associated with size of facility nor was it clearly established that regional distribution was in evidence. When iron was used as a coagulant, the concentrations of iron and aluminum were decreased. The use of iron as a coagulant was not generally found in the systems studied. Iron did appear above the detection levels and the 0.30 ppm standard in many raw waters. However, in the finished waters the percent of samples above 0.30 ppm were drastically reduced compared to raw waters.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 9
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

The Occurrence of Aluminum in Drinking Water*

EPA-600/J-84-082
JOURNAL ARTICLE

Robert G. Miller, Frederick C. Kopfler, Keith C. Kelty,
Judy A. Stober, and Nancy S. Ulmer

A random selection of 186 water utilities was used for this study in which raw and finished water samples were collected from each facility five times throughout a year and analyzed for iron and aluminum by atomic absorption techniques. The water samples were categorized by the supply source (ground, surface, or a combination of both), the type of water (raw, finished, or untreated distribution samples), and the type of coagulation used in the treatment process (aluminum sulfate, ferric chloride, other coagulants such as cationic polymers, or no coagulant). The samples were also categorized according to the 10 US Environmental Protection Agency regions and 4 population categories. The results indicate that aluminum is more likely to exist in surface waters than in groundwaters and that there is a 40-50 percent chance that alum coagulation increases the aluminum concentration of finished water above its original concentration in the raw water.

Although aluminum is one of the most abundant elements in the earth's crust and is found in human biological media, it does not appear to be necessary for sustaining life. The results of studies in which animals were exposed to aluminum under controlled conditions have demonstrated a relationship between certain neuropathological disorders and aluminum exposure.^{1,2} Recently, evidence has been presented to support the speculation that there is a relationship between aluminum and both Alzheimer's disease and dialysis encephalopathy in humans.^{3,4} Davison et al.⁵ found that kidney dialysis patients suffered dementia when their dialysis fluid contained an aluminum concentration of 80 µg/L. Removal of the aluminum from the fluid prior to dialysis decreased a patient's chance of exhibiting the symptoms of dementia. Recent studies⁶⁻⁹ have also shown that the acidification of lakes and streams by acid rain has mobilized aluminum from the soil to the aquatic environment. These elevated levels of aluminum in the water may have serious ramifications for the fish living in these waters as well as for some birds whose diets are made up of insects from the shoreline of the affected streams and lakes.⁸⁻⁹ Because of the increasing concern over the health effects associated with aluminum and the increased bioavailability of aluminum, this study was designed to determine (1) the frequency of the occurrence of aluminum in natural waters that serve as sources of drinking water and (2) whether the source was groundwater or surface water. This study also examined the

effect of coagulation with alum and other coagulants on the background concentration of aluminum in these waters.

A 1975 study¹⁰ showed that 20 percent of the water systems in the United States used coagulation on all or some of their processed water. However, the type of coagulant used, i.e., aluminum or iron, was not indicated. Barnett et al.¹¹ reported that the use of aluminum sulfate (alum) as a coagulant in the treatment of drinking water increased the aluminum concentration in the finished water. A National Academy of Science report¹² stated that a 1967 survey of 380 finished waters in the United States found aluminum in 47.8 percent of the waters treated.

Because iron was thought to be used as a coagulant by some utilities, all water samples in this study were analyzed to determine iron as well as aluminum concentrations.

Survey design

The survey used a random selection of 20 percent of the water systems from a 1000-utility sample, which was extracted from the Community Water Systems Survey Data Base.¹⁰ Water systems were categorized according to US Environmental Protection Agency (USEPA) region and population size. The population categories chosen were 25-9999, 10 000-99 999, 100 000-999 999, and ≥1 000 000. For each region, at least one utility in each of the first three population categories (if present) was chosen, and all utilities in the 1000-utility sample that serve a population of ≥1 000 000 persons were included. Alternative water utilities

were also selected based on the same criteria. The distribution of utilities in a given region is shown in Table 1; the actual number of utilities used precedes the original number of utilities chosen (in parentheses). During the course of this study, it was determined that some utilities were serving a population size different from that originally recorded in the USEPA's Community Water Systems Survey Data Base. This finding caused some shift in utilities among population categories. Other utilities chose not to participate in the survey, so the total number of participants (186) was less than originally planned (205). The geographic distribution of utilities as randomly selected is not evenly represented; region X does not have a facility serving the population category of 10 000-99 999, and regions I, IV, and X do not have a utility serving the largest population category.

The geographic distribution of the utilities that participated in this study is shown in Figure 1. A total of 1517 individual water samples was collected from 290 different water facilities of the 186 participating utilities.

Materials and sampling procedures

The sample collections were coordinated through USEPA personnel who had direct contact with the utility personnel who collected the samples. Samples were collected in October 1980, and in February, May, August, and October 1981. This pattern was chosen to detect any seasonal differences. Raw and finished water samples were to be collected during the first sampling period; only finished water samples were to be collected during the others. In most instances raw as well as finished samples were supplied for each collection date.

Samples were collected in 1-L polyethylene cubitainers after they had been rinsed with the tap water that was

*This article has been subjected to the USEPA's peer and administrative review policy and approved. Approval signifies that the contents reflect the views and policies of the USEPA. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.



Figure 1. Geographic distribution of surveyed water systems

TABLE 1
Distribution* of utilities by USEPA region and population categories

Regions	Population Served				Total
	25-9999	10 000-99 999	100 000-999 999	≥1 000 000	
I	13 (16)	4 (1)	1 (2)	0 (0)	18 (19)
II	10 (10)	2 (2)	5 (6)	1 (1)	18 (19)
III	11 (11)	1 (1)	7 (9)	2 (2)	21 (23)
IV	10 (11)	1 (2)	7 (7)	0 (0)	18 (20)
V	10 (13)	3 (2)	7 (6)	3 (2)	23 (24)
VI	7 (12)	2 (0)	1 (1)	1 (2)	11 (15)
VII	7 (8)	2 (2)	2 (2)	1 (1)	12 (13)
VIII	17 (19)	6 (4)	1 (1)	1 (0)	25 (24)
IX	21 (21)	1 (2)	3 (3)	1 (1)	26 (27)
X	12 (18)	0 (1)	2 (2)	0 (0)	14 (21)
Total	118 (139)	22 (17)	36 (39)	10 (10)	186 (205)

*Actual number of utilities precedes anticipated number given in parentheses.

TABLE 2
Number of samples, facilities, and utilities by category

Number of samples, facilities, and utilities by category						
Water	Source	Coagulant	Samples	Facilities*	Utilities*	
Untreated distribution samples	Ground	None	212	67	45	
	Surface	None	11	4	4	
Finished water	Combination†	Alum	Total 223	71	49	
		None	10	2	2	
	Ground	Alum	8	2	2	
		Alum	9	3	2	
		Iron	1	1	1	
		None	240	78	63	
	Surface	Other	5	3	3	
		Alum	271	70	44	
		Iron	56	18	7	
		None	93	25	18	
	Raw water	Combination†	Other	23	10	9
			Total 716	202	133	
		Ground	Surface	15	4	4
			Surface	210	75	51
		353	114	67		
		Total 578	193	114		

*Some facilities submitted samples in more than one source and coagulant category.
†Groundwater and surface water are both used as source.

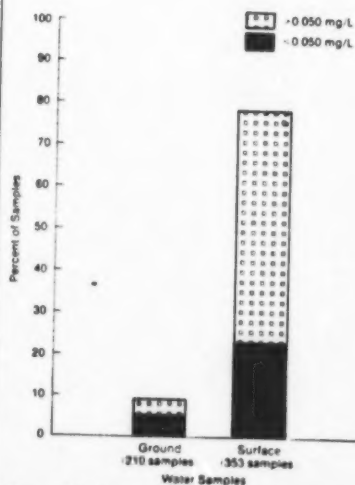


Figure 2. Percentage of raw samples with an aluminum concentration >0.014 mg/L

allowed to flow for 3 min prior to sample collection. Each cubitainer was sealed with a caplug and a screw cap, identified by a numbered information form accompanied by a questionnaire, and shipped in sample container boxes directly to the laboratory for preservation with 1.5 mL concentrated nitric acid. All samples were stored in the laboratory at 4°C until analyzed.

Analytical methods and quality control

All identifiable samples were analyzed for iron and aluminum. Iron was determined by direct aspiration using a flame atomic absorption technique,¹³ with a detection level of 0.05 mg/L. Aluminum was analyzed by the flameless atomic absorption method of Kelty et al.,¹⁴ with a detection level of 0.014 mg/L. Their method combines an ethylenediamine-tetraacetic acid-nitrate buffer solution with an acidified sample prior to analysis to eliminate interferences from calcium, fluoride, and chloride.

A rigid quality control program was followed in which more than 30 percent of the analyses pertained to precision and accuracy of the data (duplicates, spikes, and reference standards). Corresponding Shewhart's charts¹⁵ were maintained to evaluate precision and accuracy of all data.

All samples within any one collection period were analyzed together as a group. Three standard reference solutions with different aluminum concentrations (0.426 mg/L, 0.217 mg/L, and 0.350 mg/L) plus a blank water spiked with aluminum (0.1 mg/L) were analyzed with each group of samples from each sampling period throughout the year. The average recovery ranged from 95.6 to 104.1 percent. The precision of the aluminum analyses between duplicates was <0.005 mg/L.

All standard reference solutions of iron (0.796 mg/L, 0.680 mg/L, and 0.093 mg/L), spiked samples, and duplicates were in control according to Shewhart's charts for precision and accuracy. The average recovery ranged from 98.2 to 103.9 percent. The average difference between duplicate analyses of iron was consistent throughout the study (<0.02 mg/L).

Aluminum

Results. *Standard Methods*¹⁶ states: "Recent work indicates that filtered water from a modern rapid sand filtration plant should have an aluminum concentration no greater than 50 µg/L." Therefore, 0.05 mg/L was used as a reference level in the data analyses and discussion of aluminum concentrations in this study.

To examine the distribution of aluminum concentrations, the 1517 samples were categorized by their water supply source (ground, surface, or combination

TABLE 3
Aluminum concentrations in raw waters by USEPA region and population category

Category	Samples	Samples With Concentrations >0.014 mg/L			Overall Median mg/L
		Percent	Median mg/L	Maximum mg/L	
Region					
I	40	40	0.053	0.436	<0.014
II	61	38	0.059	0.398	<0.014
III	94	63	0.098	4.630	0.031
IV	61	69	0.172	2.730	0.082
V	67	51	0.084	1.420	0.016
VI	31	81	0.186	1.221	0.149
VII	39	54	0.392	5.350	0.016
VIII	85	44	0.063	0.553	<0.014
IX	96	42	0.066	2.512	<0.014
X	4	50		0.163	
Population served					
25-9999	203	30	0.066	2.512	<0.014
10 000-99 999	54	69	0.150	1.221	0.070
100 000-999 999	213	57	0.125	4.630	0.030
≥1 000 000	108	74	0.067	5.350	0.040

TABLE 4
Aluminum concentrations in finished waters by USEPA region and population category

Category	Samples	Samples With Concentrations >0.05 mg/L percent	Samples With Concentrations >0.014 mg/L			Overall Median mg/L
			percent	Median mg/L	Maximum mg/L	
Region						
I	46	13	33	0.043	0.179	<0.014
II	71	25	44	0.066	0.249	<0.014
III	123	37	54	0.070	2.670	0.022
IV	80	54	68	0.161	0.449	0.060
V	100	51	64	0.082	2.160	0.051
VI	35	29	60	0.040	0.889	0.029
VII	53	2	13	0.026	0.051	<0.014
VIII	105	30	47	0.083	2.580	<0.014
IX	89	29	52	0.053	1.167	0.020
X	14	0	7			<0.014
Population served						
25-9999	286	15	28	0.051	1.167	<0.014
10 000-99 999	92	39	61	0.087	2.580	0.023
100 000-999 999	222	48	66	0.094	2.670	0.045
≥1 000 000	116	38	62	0.058	0.402	0.033

TABLE 5
Distribution of aluminum concentrations (mg/L) in finished waters*

Source	Coagulant	Distribution				
		Minimum	25 Percent	Median	75 Percent	Maximum
Ground	None	0.014	0.021	0.031	0.051	0.290
Surface	None	0.016	0.026	0.043	0.098	1.167
	Alum	0.014	0.054	0.112	0.219	2.670
	Iron	0.015	0.030	0.038	0.050	0.081
	Other	0.016				0.041

*Includes only samples with concentrations above detection limit (0.014 mg/L)

of both), the type of water sample (raw, finished, or untreated distribution samples), and the type of coagulant used (aluminum sulfate, ferric chloride, other coagulants such as cationic polymers, or no coagulant). The distribution of aluminum concentrations was also examined for each of the five sampling periods to determine possible seasonal variations. This was done by comparing, among sampling periods, the percentage of samples with aluminum concentrations above the detection limit (0.014

mg/L), the percentage with concentrations >0.050 mg/L, and the quintile values within each category for each sampling period. There were no obvious seasonal patterns; therefore, the data from all five sampling periods were combined by category for analysis.

The number of samples and the number of utilities and facilities supplying water samples in each category are shown in Table 2. Because of the small number of samples in some categories, the presentation of data analysis was

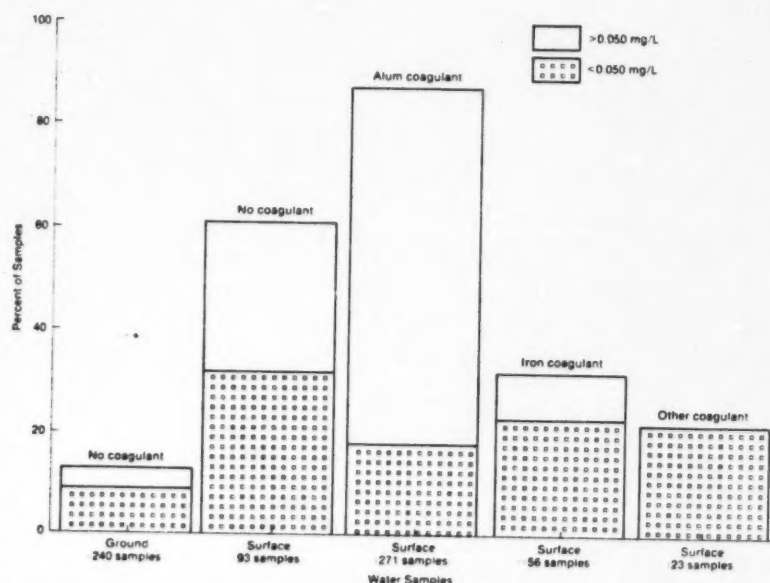


Figure 3. Percentage of finished samples with an aluminum concentration >0.014 mg/L (all rounds)

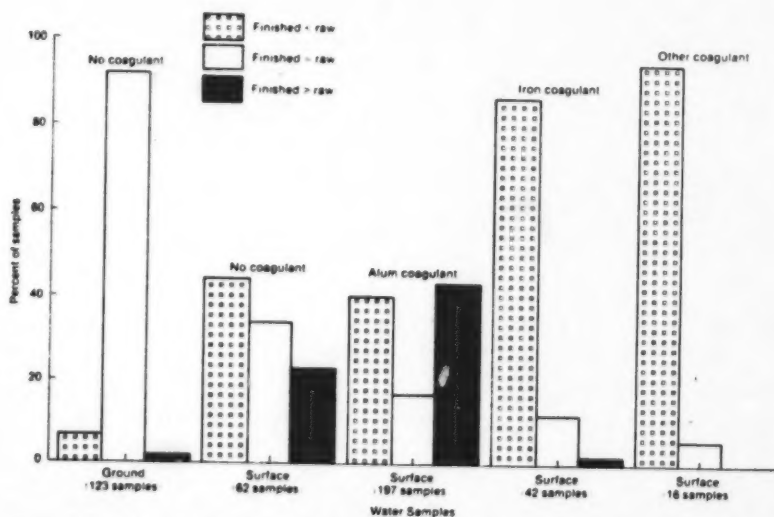


Figure 4. Paired samples—aluminum concentrations of finished and raw samples

restricted to those categories that had 20 or more samples.

Raw waters. The distribution of raw water samples by regions and their combined population categories is given in Table 3. There were too few samples from region X for those data to be considered. For the samples with aluminum concentrations >0.014 mg/L (detection limit), the median value for each region and population category was ≥ 0.05 mg/L. Of the 578 raw samples collected, 52 percent or 299 had concen-

trations of aluminum ≥ 0.014 mg/L. In region VI, 81 percent of the raw water samples had aluminum concentrations above the detection limit. In the population category of 25-9999, 70 percent of the raw samples had aluminum concentrations below the detection level. Figure 2 shows the frequency of detectable aluminum concentrations and the frequency of concentrations >0.05 mg/L for each source of raw water. Fifty-five percent of the raw surface waters had aluminum concentrations >0.05 mg/L,

whereas only 4 percent of the raw groundwaters had aluminum concentrations >0.05 mg/L. Several surface water samples had relatively high aluminum concentrations (>2.5 mg/L).

Finished waters. Table 4 shows, for each region and population category, the number of finished water samples collected, the frequency of an aluminum concentration >0.05 mg/L, the percentage of samples and the median and maximum aluminum concentrations for samples of finished water with concentrations above the detection level, and the median concentration for all finished water samples. Except for region VII, more than 30 percent of the samples from each region had concentrations above the detection limit. There were too few samples from region X to be considered. More than 50 percent of the finished water samples from regions IV and V had aluminum concentrations >0.05 mg/L. The overall median of the detectable aluminum concentrations was highest in region IV. Samples from regions IV and V had the highest overall median value for all finished water samples (>0.05 mg/L). Finished water samples from utilities serving populations of fewer than 10 000 persons had the lowest frequency of detectable aluminum levels, the lowest frequency of aluminum concentrations >0.05 mg/L, and the lowest median value for samples above the detection limit.

Figure 3 shows the frequency of detectable aluminum concentrations in finished water samples and the frequency of concentrations >0.05 mg/L for each source and coagulant category. Sixty-nine percent of the finished surface waters that had been coagulated with alum had aluminum concentrations >0.05 mg/L. Twenty-nine percent of the samples of finished surface water that had not been coagulated had an aluminum concentration >0.05 mg/L. Only 9 percent of finished surface waters that had been coagulated with iron had an aluminum concentration >0.05 mg/L. Of the 240 finished groundwater samples, 13 percent had detectable aluminum and only 4 percent had concentrations >0.05 mg/L. Table 5 shows the distribution of detectable aluminum concentrations in finished water samples by source and type of coagulant.

Table 6 shows the number of utilities and facilities with aluminum concentrations >0.05 mg/L in finished waters. Of the 70 facilities using surface water and coagulating with alum, 36 had an aluminum concentration >0.05 mg/L in their finished water samples for three or more collection periods.

Untreated distribution samples. Table 7 shows the untreated distribution samples as they were reported by region and population category. In no region or population category were concentrations

TABLE 6
Number of utilities and facilities with aluminum concentrations >0.05 mg/L in finished waters

Source	Coagulant	Utilities*	Utilities With Concentrations >0.05 mg/L†	Facilities*	Facilities With Concentrations >0.05 mg/L†	Facilities With Concentrations Consistently >0.05 mg/L‡
Ground	None	63	7	78	8	0
Surface	None	18	9	25	13	4
	Alum	44	39	70	63	36
	Iron	7	3	18	4	0
	Other	9	0	10	0	0

*Some utilities and facilities submitted samples in more than one category.

†At least one sample had a concentration >0.05 mg/L.

‡Samples from three or more collection periods had a concentration >0.05 mg/L.

TABLE 7
Occurrence of aluminum in waters not treated prior to distribution

Category	Samples	Samples With Concentrations >0.014 mg/L	Samples With Concentrations >0.05 mg/L
Region			
I	17	4	2
II	19	3	2
III	3	0	0
IV	10	1	0
V	21	2	2
VI	8	2	0
VII	3	0	0
VIII	30	0	0
IX	95	11	4
X	17	4	0
Population served			
25-9999	175	18	4
10 000-99 999	5	0	0
100 000-999 999	43	9	6
≥1 000 000	0	0	0

TABLE 8
Number of facilities and utilities submitting paired samples*

Source	Coagulant	Samples	Facilities†	Utilities†
Ground	Alum	6	3	2
	Iron	1	1	1
	None	123	49	38
Surface	Other	4	2	2
	Alum	197	68	44
	Iron	42	18	7
	None	62	21	15
Combination	Other	16	9	8
	Alum	8	2	2
	None	7	2	2
Total		466	167	105

*Raw and finished water samples collected on the same date at the same facility.

†Some facilities and utilities submitted samples in more than one category.

TABLE 9
Iron concentrations in raw waters by USEPA region and population category

Category	Samples	Samples With Concentrations >0.05 mg/L			Overall Median mg/L
		percent	Median mg/L	Maximum mg/L	
Region					
I	40	50	0.115	0.5	0.03
II	61	56	0.13	6.1	0.06
III	94	69	0.31	2.37	0.13
IV	61	79	0.35	2.08	0.27
V	67	67	0.18	3.0	0.11
VI	31	94	0.39	7.68	0.38
VII	39	79	0.96	7.88	0.78
VIII	85	54	0.195	9.06	0.06
IX	96	71	0.25	3.7	0.11
X	4	50		0.21	0.095
Population served					
25-9999	203	63	0.265	7.68	0.09
10 000-99 999	54	87	0.43	9.06	0.355
100 000-999 999	213	62	0.295	7.88	0.08
≥1 000 000	108	75	0.15	7.33	0.11

in more than 25 percent of the untreated samples above the detection limit of aluminum. Overall, 10 percent of these samples had aluminum concentrations >0.014 mg/L, and 3 percent had aluminum levels >0.05 mg/L.

Paired samples. In order to examine what effect the treatment process might have on the aluminum concentration of the water, concentrations in raw and finished water samples collected on the same date in a facility were compared. Table 8 shows the number of paired samples by water source and coagulant category. There were 466 matched raw and finished water samples from 167 facilities in 105 utilities. Figure 4 shows, for each source and coagulant type, the percentage of paired samples in which the aluminum concentration in finished water was less than that in raw water, the percentage in which the finished concentration equaled the raw concentration, and the percentage in which the finished concentration was greater than the raw concentration. If the aluminum concentration of the finished water sample was within 10 percent of the raw water level or within one half the detection level (± 0.007 mg/L), the finished concentration was considered equal to the raw concentration.

There were 197 paired surface water samples that had been coagulated with alum. For 43 percent of these, the aluminum concentration increased during the treatment process. One hundred thirty-six (69 percent) of the pairs had finished aluminum concentrations >0.05 mg/L; 61 percent of these had been increased in the treatment process, and 30 percent had been decreased. The increase ranged from 0.01 to 2.37 mg/L, and the decrease ranged from -0.02 to -3.7 mg/L. The aluminum concentration of the raw water had been above the detection limit in 73 percent of the pairs in which the aluminum increased. The paired samples in which the aluminum level increased were from 45 different facilities in 31 water utilities.

The 14 samples of surface water that were not subjected to coagulation and showed an increase in aluminum concentration were from nine facilities in six utilities. Two thirds of the samples were from one utility on two different dates. Eleven of the 14 samples (79 percent) had finished aluminum concentrations >0.05 mg/L, whereas only 5 samples (36 percent) had raw water concentrations >0.05 mg/L.

Iron

Raw waters. The iron concentration of the water samples was analyzed mainly to determine the effect coagulation with iron had on the iron concentration of the water. Table 9 lists by region and by population category the percentage of raw water samples with iron concentra-

tions above the detection limit (0.05 mg/L), the median and maximum iron concentrations for those above the detection level, and the median iron value for all raw waters. More than 50 percent of the raw water samples from all regions and all population categories had iron concentrations >0.05 mg/L. The maximum iron concentration in a region ranged from 0.21 mg/L in region X to 9.06 mg/L in region VIII.

The overall median iron concentration for all samples was 0.10 mg/L. Iron concentrations in 52 percent of the raw water samples from ground sources and in 76 percent of the raw water samples from surface sources were >0.05 mg/L. For both sources, 50 percent of these samples had iron concentrations >0.26 mg/L.

Finished waters. Table 10 shows for each region and each population category the percentage of finished water samples having iron concentrations above the detection limit, the percentage above the secondary standard (0.3 mg/L), the median and maximum concentrations of those above the detection level, and the overall median value. With the exception of region IV, all regions and all population categories had samples with iron concentrations above the secondary standard. Samples from utilities servicing populations of fewer than 10 000 persons had the highest frequency of concentrations above the standard (12 percent).

Figure 5 shows the frequency of detectable iron concentrations in finished water samples and the frequency of concentrations above the secondary standard for each source and coagulant category. Finished samples of uncoagulated waters had the highest frequency of concentrations above the detection limit and the highest frequency of concentrations above the standard (52 percent and 13 percent, respectively, for groundwaters and 62 percent and 10 percent for surface waters). Only 2 percent of the samples that had been coagulated with iron had finished iron concentrations greater than the standard.

Only groundwaters and surface waters not subjected to coagulation had overall median concentrations above the detection limit. The distribution of iron concentrations exceeding the detection limit is shown in Table 11. Only one facility using iron coagulation had a finished sample with an iron concentration exceeding the standard, whereas approximately 20 percent of those facilities not using a coagulant had at least one sample with an iron concentration above the standard (Table 12). Five facilities (6 percent) that used groundwater had three or more samples from different sampling periods with concentrations >0.3 mg/L.

Untreated distribution samples. The frequency of untreated distribution sam-

TABLE 10
Iron concentrations in finished waters by USEPA region and population category

Category	Samples	Samples With Concentrations >0.05 mg/L*			Samples With Concentrations >0.3 mg/L† percent	Overall Median mg/L
		percent	Median mg/L	Maximum mg/L		
Region						
I	46	54	0.14	4.63	11	0.06
II	71	47	0.12	1.06	4	<0.05
III	123	37	0.09	1.44	5	<0.05
IV	80	14	0.07	0.26	0	<0.05
V	100	28	0.14	0.54	9	<0.05
VI	35	63	0.16	0.76	11	0.08
VII	53	23	0.11	0.34	2	<0.05
VIII	105	30	0.16	6.38	8	<0.05
IX	89	34	0.12	2.68	6	<0.05
X	14	43	0.32	0.49	29	<0.05
Population served						
25-9999	286	50	0.14	2.68	12	<0.05
10 000-99 999	92	26	0.18	6.38	7	<0.05
100 000-999 999	222	24	0.10	1.06	1	<0.05
≥1 000 000	116	22	0.07	0.41	2	<0.05

*Detection limit

†Secondary standard

TABLE 11
Distribution of iron concentrations (mg/L) in finished waters*

Source	Coagulant	Distribution				
		Minimum	25 Percent	Median	75 Percent	Maximum
Ground Surface	None	0.05	0.08	0.14	0.30	4.63
	None	0.05	0.08	0.12	0.20	2.68
	Alum	0.05	0.06	0.08	0.17	6.38
	Iron	0.06	0.06	0.08	0.12	0.41
	Other	0.05				0.18

*Includes only samples with concentrations above the detection limit (0.05 mg/L)

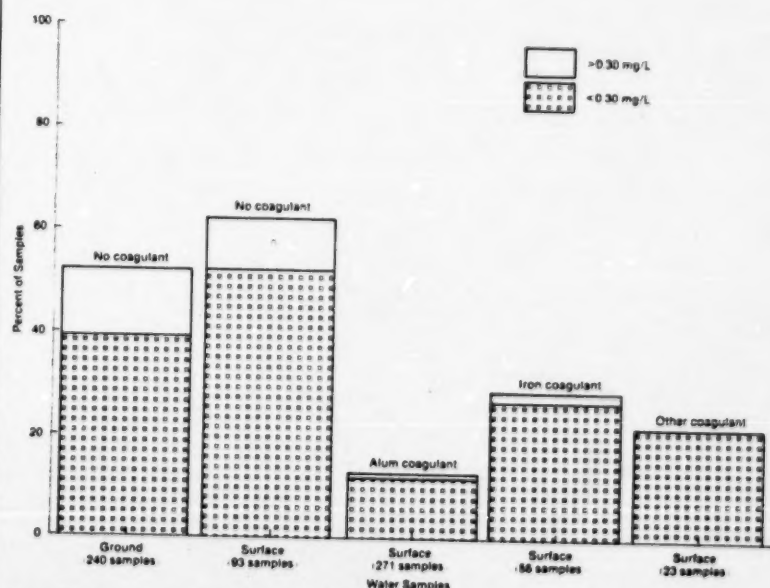


Figure 5. Percentage of finished samples with an iron concentration >0.05 mg/L (all rounds)

TABLE 12
Number of utilities and facilities with iron concentrations >0.30 mg/L in finished waters

Source	Coagulant	Utilities*	Utilities With Concentrations >0.3 mg/L†	Facilities*	Facilities With Concentrations >0.3 mg/L†	Facilities With Concentrations Consistently >0.3 mg/L‡
Ground	None	63	14	78	15	5
Surface	None	18	5	25	5	1
	Alum	44	3	70	3	0
	Iron	7	1	18	1	0
	Other	9	0	10	0	0

*Some facilities and utilities submitted samples in more than one category.

†At least one value >0.30 mg/L.

‡Samples from three or more sampling periods had iron values >0.3 mg/L.

TABLE 13
Occurrence of iron in waters not treated prior to distribution

Category	Samples	Samples With Concentrations >0.05 mg/L*	Samples With Concentrations >0.3 mg/L†
Region			
I	17	5	0
II	19	16	2
III	3	0	0
IV	10	8	4
V	21	7	3
VI	8	4	0
VII	3	0	0
VIII	30	12	10
IX	95	27	2
X	17	4	0
Population served			
25-9999	175	70	19
10 000-99 999	5	0	0
100 000-999 999	43	13	2
≥1 000 000	0	0	0

*Detection limit

†Secondary standard

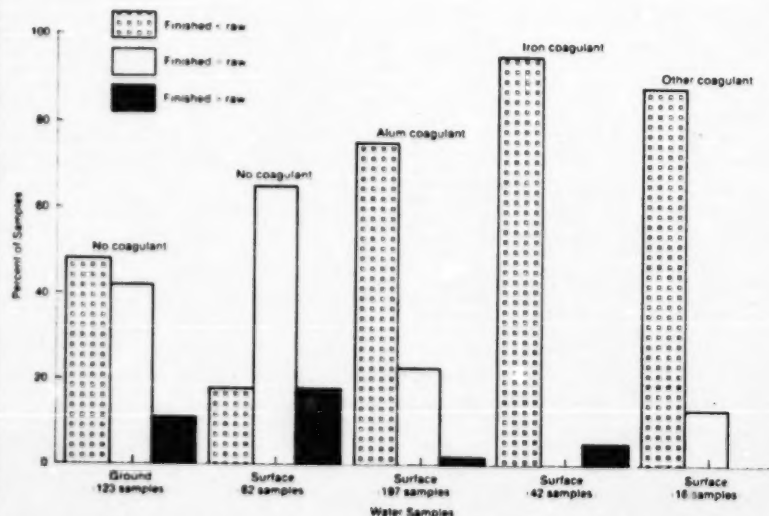


Figure 6. Paired samples—iron concentrations of finished versus raw samples

ples with concentrations above the detection limit and the frequency of samples with concentrations above the standard are shown in Table 13, for each region and for each population category. Forty percent of the samples from the smallest population category had concentrations above the detection limit, and 11 percent had concentrations above the standard. Only three regions (V, VIII, and IX) had more than 20 samples. Two percent to 33 percent of the samples from these regions had iron concentrations exceeding the standard.

Thirty percent of the groundwater samples had iron concentrations above the detection limit, and 10 percent had concentrations above the standard.

Paired samples. Matched raw and finished water iron concentrations are compared in Figure 6. The finished iron concentration was considered equal to the raw concentration if it was within 10 percent of the raw water value or within half of the detection level (± 0.025 mg/L). Those samples that had not been subjected to coagulation had the largest frequency of increased iron concentration during the treatment process (groundwater iron increased 11 percent, and surface water iron increased 18 percent). Two surface water samples coagulated with iron had increased iron concentrations, but neither of the finished iron levels were above the standard. In the 19 samples with finished iron concentrations above the standard, there was no difference in the percent in which iron levels decreased, remained the same, or increased during the treatment process. Thirteen samples (68 percent) with finished iron concentrations above the standard were from facilities in the smallest population category (25-9999).

Conclusions

This study has presented data on the source of aluminum in drinking water supplies, indicating that aluminum routinely exists in drinking water. The data show that aluminum is more likely to exist in surface waters than in groundwaters; only 9 percent of the groundwaters had detectable amounts of aluminum, whereas 78 percent of the surface waters had detectable aluminum.

In finished waters, aluminum concentrations were routinely above the detection level of 0.014 mg/L. The data also indicate that when alum is used for coagulation, there is a 40-50 percent chance that the concentration of aluminum will increase above the original concentration in raw water.

The concentration of aluminum in finished water does not seem to be associated with size of facility or region.

In the few facilities that used iron as a coagulant, the concentrations of iron and aluminum decreased. The use of

iron as a coagulant was not generally found in the systems studied. Iron was present at concentrations above the detection level and the 0.30-mg/L secondary standard in many raw waters. In the finished waters, however, the percentage of samples with concentrations >0.30 mg/L was drastically reduced.

References

1. KOPELOFF, L.M.; BARRERA, S.E.; & KOPELOFF, N. Recurrent Convulsive Seizures in Animals Produced by Immunologic and Chemical Means. *Amer. Jour. Psychiatry*, 98:881 (1942).
2. KLATZO, I.; WISNIEWSKI, H.; & STREICHER, E. Experimental Production of Neurofibrillary Degeneration. *Jour. Neuropathol. Exp. Neurol.*, 24:187 (1965).
3. CRAPPER, D.R.; KRISHNAN, S.S.; & DALTON, A.J. Brain Aluminum in Alzheimer's Disease and Experimental Neurofibrillary Degeneration. *Sci.*, 180:511 (1973).
4. *Aluminum Neurotoxicity* (L. Liss, editor). Pathotox Publ., Inc., Park Forest South, Ill. (1980).
5. DAVISON, A.M. ET AL. Water Supply Aluminum Concentration Dialysis Dementia, and Effect of Reverse Osmosis Water Treatment. *Lancet*, 785 (Oct. 9, 1982).
6. JOHNSON, N.M. Acid Rain: Neutralization Within the Hubbard Brook Ecosystem and Regional Implications. *Sci.*, 204:497 (1979).
7. CRONAN, C.S. & SCHOFIELD, C.L. Aluminum Leaching Response to Acid Precipitation: Effect on High-Elevation Watersheds in the Northeast. *Sci.*, 204:304 (1979).
8. DRISCOLL, C.T. ET AL. Effect of Aluminum Speciation on Fish in Diluted Acidified Water. *Nature*, 284:161 (Mar. 12, 1982).
9. NYHOLM, N.E.I. Evidence of Involvement of Aluminum in Causation of Defective Formation of Eggshells and of Impaired Breeding in Wild Passerine Birds. *Envir. Res.*, 26:363 (1981).
10. HERSHELL, E. Survey of Operating and Financial Characteristics of Commercial Water Systems. Rept. 570/9-77-003. USEPA, Washington, D.C. (1977).
11. BARNETT, P.R.; SKORRGSTAD, M.W.; & MILLER, K.J. Chemical Characterization of a Public Water Supply. *Jour. AWWA*, 61:2:60 (Feb. 1969).
12. *Drinking Water and Health*. Natl. Acad. of Sci., Washington, D.C. (1977).
13. *Methods for Chemical Analysis of Water and Wastes*. Rept. 600/4-79-020. USEPA, Cincinnati, Ohio (Mar. 1979).
14. KELTY, K.C. ET AL. Analysis of Aluminum in Water by Flameless Atomic Absorption Spectrophotometry. *Proc. AWWA WQTC*, Seattle, Wash. (Dec. 1981).
15. *Handbook for Analytical Quality Control in Water and Wastewater Laboratories*. Rept. 600/4-79-019. USEPA, Cincinnati, Ohio (Mar. 1979).
16. *Standard Methods for the Examination of Water and Wastewater*. APHA, AWWA, and WPCF. Washington, D.C. (14th ed., 1976).

About the author:

A research chemist-biochemist for the US government for 23 years, Robert G. Miller has spent the past 10 years on research in analytical chemistry, with particular emphasis on trace metals in drinking water and biological tissues. He is a research chemist, Frederick C. Kopfler is a supervisory chemist, Keith C. Kelty is a chemist, and Judy A. Stober is a mathematical statistician, Chemical and Statistical Support Branch, Toxicology and Microbiology Division, Health Effects Research Laboratory, USEPA, 26 West St. Clair Street, Cincinnati, OH 45268. Nancy S. Ulmer is a research chemist, Municipal Environmental Research Laboratory, USEPA, 26 West St. Clair Street, Cincinnati, OH 45268.

